Renewable and Sustainable Energy Reviews 16 (2012) 2278–2288

Contents lists available at SciVerse ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

An overview of ocean renewable energy resources in Korea

Gunwoo Kim[a], Myung Eun Lee[b,*], Kwang Soo Lee[c], Jin-Soon Park[c], Weon Mu Jeong[c], Sok Kuh Kang[d], Jae-Gwi Soh[d], Hanna Kim[d]

[a] *Department of Ocean Civil & Plant Construction Engineering, Mokpo National Maritime University, Mokpo 530-729, Republic of Korea*
[b] *Department of Civil and Environmental Engineering, Seoul National University, Seoul 151-742, Republic of Korea*
[c] *Coastal Engineering & Ocean Energy Research Department, Korea Ocean Research & Development Institute, Ansan, Gyunggi 426-744, Republic of Korea*
[d] *Climate Change & Coastal Disaster Research Department, Korea Ocean Research & Development Institute, Ansan, Gyunggi 426-744, Republic of Korea*

ARTICLE INFO

Article history:
Received 18 June 2011
Received in revised form 9 January 2012
Accepted 10 January 2012
Available online 18 February 2012

Keywords:
Renewable energy
Wave energy
Tidal energy
Tidal current energy
Ocean thermal energy

ABSTRACT

Korea relies on imported fossil fuels to meet its energy consumption demands. As such, there is a need to investigate alternative energy resources such as renewable energy. In this paper, assessments of the potential of various ocean renewable energy resources in the sea around Korea; potential sources of energy including wave energy, tidal energy, tidal current energy and ocean thermal energy. Tidal energy and tidal current energy are likely to play an important role in meeting the future energy needs of Korea, whereas the potentials of wave energy and ocean thermal energy for the same are relatively low. The level of technical development and the renewable energy market in Korea is currently in an early stage. The government will have to be more aggressive in the promotion of renewable energy to achieve sustainable development in Korea.

Contents

1. Introduction

The economy of the Republic of Korea (hereafter referred to as "Korea") has been growing rapidly for the last 30 years. Because of the limited domestic energy resources, Korea has been almost entirely dependent on imports to meet its energy consumption needs. In the early years, the imported energy resources were mostly fossil resources such as petroleum and coal. Even after two oil crises, fossil resources still represent a significant share of the total energy resources. It is well known that these fossil resources are gradually being depleted, resulting in reduced price stability. In addition, CO_2 emissions caused by the consumption of massive

* Corresponding author. Tel.: +82 2 880 8270; fax: +82 2 873 2684.
E-mail address: lmeun88@snu.ac.kr (M.E. Lee).

1364-0321/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
doi:10.1016/j.rser.2012.01.040

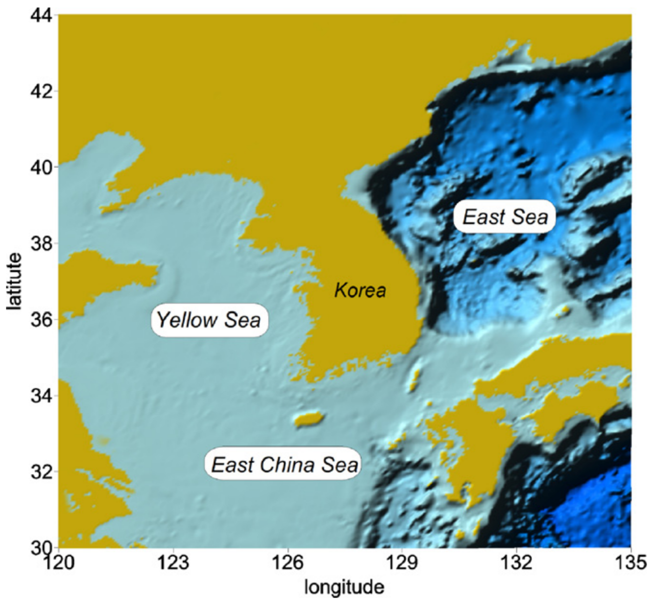

Fig. 1. Map of the Korean Peninsula showing the geographical situation.

amounts of fossil energy have a great influence on the global environment. Nuclear energy, which is still relatively low cost, carries potential risk of catastrophe through contamination resulting from radiation leakage accident. In this context, reducing the dependence on these traditional energy sources and preserving the environment have become significant goals for all human beings.

Renewable energies have the potential to overcome the gradual depletion of traditional fossil energies and their associated environmental impacts, while simultaneously solving the issues of energy sustainability, economic development, and environmental protection; consequently, the development and application of renewable energies have accelerated during the last decade. Among the renewable energies, ocean energy refers to that carried by ocean waves, tides, and ocean temperature differences. The ocean has a tremendous amount of energy as it covers more than 70% of the Earth's surface, making it the world's largest solar collector. In addition, tidal and wave energy driven by the gravitational pull of the moon and by the winds, respectively, are substantial energy resources in the ocean.

An assessment of the potentials of ocean energy is not only a basic prerequisite for the planning of its utilization and the selection of available sites, but is also an important requirement for choosing the most appropriate energy converter for the area and designing the converter's capacity. Despite this, details of the ocean energy resources around Korea remain poorly defined. Fig. 1 shows the geographical situation of Korea. Korea is located at the southern part of the Korean Peninsula which is surrounded by the Yellow Sea, East China Sea and East Sea. The Yellow Sea is located between Mainland China and the Korean Peninsula and its tides are high on the coast of the Korean Peninsula, typically ranging between 4 and 8 m, which enable the utilization of tidal power. Furthermore, ria coasts formed by the partial submergence of a river valley have developed on the south-western coast. Therefore, the high tidal range in Yellow Sea coupled with the ria coasts has led to rapid tidal current at several locations, which suggests the possibility of the utilization of tidal current power. In addition, Korea is located in temperate zones where most of the wave energy potentials are expected as a result of the prevailing westerlies in these zones in winter.

There have been many research projects to utilize ocean energy resources in Korea. First of all, the tidal energy attracted intermittent interest since the Japan's first survey [1] in 1930s. For the other resources, KORDI (Korea Ocean Research & Development Institute) [2] and KEPKO (Korea Electric Power Corporation) [3] conducted the first feasibility study on the ocean thermal energy and the wave energy in 1990s. Since 2000s, KORDI has taken the lead in the field of the survey of ocean energy resources and the development of energy converter in Korea. On the other hand, the field observations have been separately carried out by various research institutes such as KORDI, KHOA (Korea Hydrographic & Oceanographic Administration), and NFRDI (National Fisheries Research & Development Institute). Therefore, all of the information had not yet been fully integrated.

To date, the ocean energy potentials around Korea have been partially assessed by various research projects and field observations by KORDI, KHOA and NFRDI. Recently, the Ministry of Knowledge Economy embarked on an R&D project of *Study of the Distribution of Ocean Energy Resources in the Southern Sea of Korea* [4] that was conducted by KORDI. This project is expected to be the starting point of an integrated study of Korean ocean energy. Another endeavor by the government is also being carried out: *New & Renewable Energy White Book* [5] has been published biennially by the Ministry of Knowledge Economy. This book documents recent advances in the field of renewable and sustainable energy development in Korea.

In this review, we summarized and introduced the results of historical and recent R&D projects with respect to the ocean energy utilization in Korea. First, the current situation and the trend of energy resources in Korea are discussed. Next, the energy potentials, ongoing projects, and future prospects of ocean energy resources are introduced for each energy resource. The article will end with some conclusions and suggestions regarding the commercialization of Korea's ocean energy.

2. Current situation of energy in Korea

The total energy consumptions in Korea has increased from 45.7 million tons of oil equivalent (Mtoe) in 1981 to 242.2 Mtoe in 2009 with an average annual growth rate of 6.1% [5,6]. Furthermore, Korea is highly dependent on petroleum and coal in its energy mix (Table 1), with these energy forms together accounting for 70.5%

Table 1
Primary energy consumption trend.

Year	1981	1990	1997	1998	2009
Coal	15,244 (33.3)	24,385 (26.2)	34,799 (19.3)	36,039 (21.7)	68,600 (28.3)
Petroleum	26,580 (58.1)	50,175 (53.8)	109,080 (60.4)	90,582 (54.6)	102,300 (42.2)
LNG	–	3023 (3.2)	14,792 (8.2)	13,838 (8.3)	32,300 (13.3)
Hydro power	677 (1.5)	1590 (1.7)	1351 (0.7)	1525 (0.9)	1200 (0.5)
Nuclear	724 (1.6)	13,222 (14.2)	19,272 (10.7)	22,422 (13.5)	31,800 (13.1)
New and renewable	2492 (5.5)	797 (0.9)	1344 (0.7)	1526 (0.9)	6000 (2.5)
Total	45,717 (100.0)	93,192 (100.0)	180,638 (100.0)	165,932 (100.0)	242,200 (100.0)

Units: Mtoe (%).

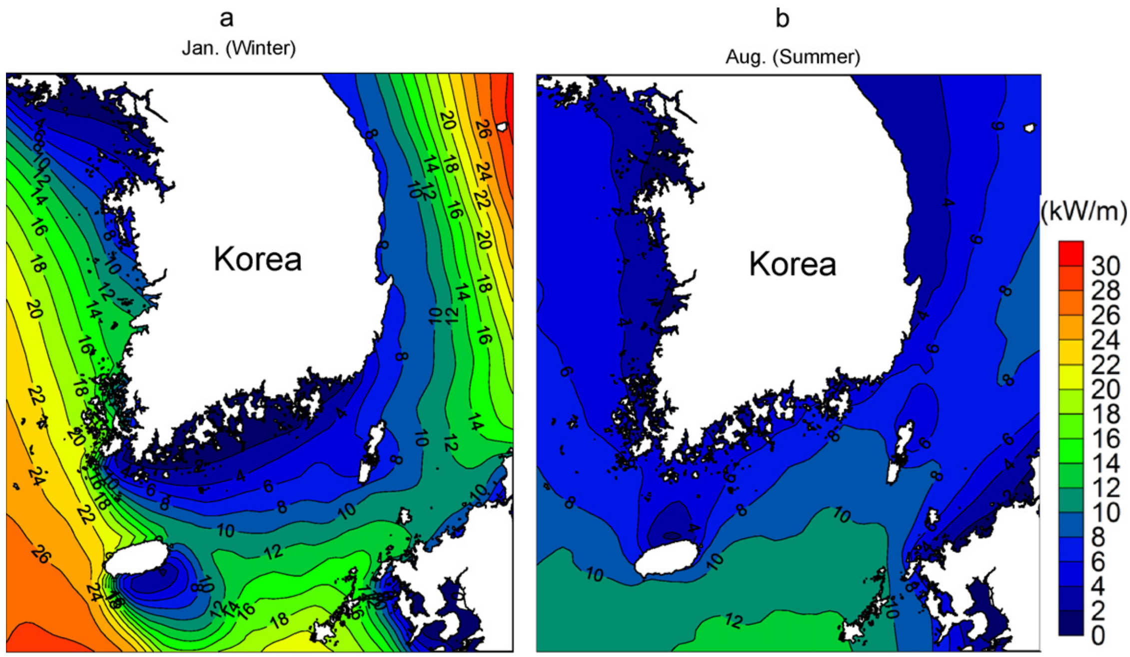

Fig. 2. Monthly averaged wave power density (kW/m); (a) January (winter), (b) August (summer).

of the total energy supply in 2009. Crude oil dominated the primary energy consumption composition of Korea, accounting for 60.4% in 1997, but its dependency dropped continuously down to 42.2% in 2009. The reduced portion was picked up mostly by natural gas and nuclear power because the government encouraged it for environmental protection and convenience. Nuclear energy and LNG contributed 13.1% and 13.3%, respectively, to the total energy supply in 2009. Although the dominant source of energy is shifting in Korea, the country's heavy dependence on foreign supply remains unchanged. The remaining 3.0% of energy supply has been supplied by hydro power and renewable energy. Even though the consumption of renewable energy has increased at an average annual growth rate of 11.2% during this period, the share of total energy consumption is only 2.5% except for the hydro power.

From 1981 to 1997, the increase rate of energy consumption was higher than the rate of economic growth, because high economic growth during this period was mainly dependent on high energy – consuming industries such as steel, shipbuilding, chemical production, and cement, which started as part of government-led industrialization. Since 1997, the economic growth rate has slowed down at an average annual rate of 5.7%. As a result, the rate of total energy consumption has also decreased at an average annual rate of 4.4%. The lower economic growth rate started with the financial crisis in Korea in 1998. At the same time, the concurrent change in the industrial structure because of the financial crisis improved the energy efficiency. Furthermore, the change in the industrial structure since the financial crisis, the improvement of energy efficiency, and the change in the industrial structure toward low-energy consumption industry, such as the information and communication technology and service industry slowed down energy consumption growth.

With the recent high oil prices, a sense of energy crisis resulting from the imbalance between the production and consumption of petroleum is spreading. In addition, discussions regarding enforcing green-house gas reduction have become another theme of the current global energy strategy and negotiating the post-Kyoto Protocol is beginning [7,8]. In order to prepare for these new resource circumstances, the government established a National Energy Master Plan [9], in which the proportion of new and renewable energy is planned to be increased more than 11% by 2030. According to this plan, a more detailed and integrated investigation and assessment of the potentials of Korea's renewable energy have become one of the most important needs of the times.

3. Wave energy

In this section, we reviewed the wave energy assessment [10] around the Korean peninsula obtained from hindcast wave data for the period of 1979–2003. Recent R&D projects conducted in Korea to harness the wave energy are also briefly introduced.

3.1. Hindcast wave data

The wave energy is the most unpredictable among various ocean renewable energy resources because waves are generated by winds that have very high variability. Thus, the wave energy potential is generally computed based on the long-term data. However, most wave observation does not cover the entire interest region and the observation data are, in general, not obtained for a long enough period to offset its annual variability. Therefore, the offshore wave energy is generally assessed by hindcast wave data, which provide the temporally consistent and full spatial coverage required for wave energy assessment. Recently, the wave energy potentials around the Korean peninsula were obtained by integrating the hindcast data [11] for the period of 1979–2003 [10]. The data contains the significant wave height, peak period, and direction for each grid point of the regional seas in northeast Asia with a grid size of 1/6° (approximately 18 km) covering a longitude of 117–143°E and latitude of 20–50°N with a frequency of 1 h. The wind field used in the wave simulation was the re-analyzed data obtained by European Centre for Medium-Range Weather Forecasts (ECMWF). The second-generation wave model, HYPA [12], was used in the wave simulation for the normal condition, whereas the third-generation wave model, WAM [13], was used for the extreme storm condition.

3.2. Assessment of wave energy potentials

The offshore wave power can be obtained directly from hindcast wave data using the following deep water expression

$$P = \frac{\rho g^2 T_E H_s^2}{64\pi} \tag{1}$$

where ρ is the seawater density, g is the gravitational acceleration, P is the wave power, T_E is the energy period, and H_s is the significant wave height. The energy period is rarely specified and must be calculated from other periods. Measured seastates are generally specified in terms of the peak period T_p. The relation between T_E and T_p depends on the shape of the wave spectrum and can be expressed as $T_E = 0.9T_p$, which was obtained by numerical integration of the JONSWAP wave spectrum derived for growing wind waves in deep water.

Based on Eq. (1) and hindcast wave data, the spatial distributions of the seasonal average of wave energy density around Korea were depicted in Fig. 2. Fig. 2(a) showed that relatively high wave energy reaching 25 kW/m occurs in winter on the south-western coasts of Korea owing to the northwestern seasonal monsoon. However, even in winter, the wave energy on the eastern coast of Korea is sheltered from the winter monsoon by the mainland. Fig. 2(b) shows that the wave energy in summer is relatively low because the Westerly becomes weaker and North Pacific anticyclone prevailed, which does not induce high wave around Korea.

Wave energy potentials around Korea are much less than those of the countries with the highest wave energy density such as the UK and Portugal. However, it is expected that the relatively higher wave energy in winter can be utilized for heat supply in many small islands located on the south-western coast of Korea. In the white paper [4], the theoretical power of wave energy resources along Korea's coastline are roughly computed up to 9979 MW, but utilization of the entire amount of energy is not practical because of the efficiency of the wave energy converter and the usage of seawater surface for fisheries, seafood farming and maritime national park.

3.3. Development status of wave energy converter in Korea

The technical research of wave energy development in Korea began in the 1990s, but the technology remains in a premature level. Government-supported research institutes and academia are playing a leading role in the technical development, whereas the participation of industrial companies is very slight. This is because the detailed information of wave power potentials around Korea was not clearly assessed and the government did not support renewable energy technology. However, as the commercialization of wave power utilization is underway, the interests in relating companies are expected to increase.

KORDI has took the lead in the field of wave energy development in Korea, and attempted the test generation using a 60 kW ocean wave energy conversion device of floating Oscillating Water Column (OWC) type, Jujeon A (Fig. 3), in the field in July 2001, but it failed due to a storm sweep [14]. KORDI also developed an overtopping-type wave energy conversion device (Fig. 4) [15]. In 2007, a floating Backwater Bent Duct Buoy (BBDB)-type wave energy converter was developed and a pilot test was also conducted (Fig. 5) [16]. Recently, research projects of caisson-type oscillating water column wave energy conversion devices of 500 kW are underway and a pilot wave power plant is being constructed (Fig. 6) in the western sea of Jeju Island [17]. Details of the research project for the wave energy converter in Korea are listed in Table 2. Recently, HSTWEC (hydrostatic transmission-based wave energy converter) [18] was introduced as an innovative floating-buoy WEC.

Fig. 3. Oscillating water column type wave energy converter, Jujeon A.

Fig. 4. Laboratory test of overtopping-type wave energy converter.

Fig. 5. Backwater Bent Duct Buoy type wave energy converter.

4. Tidal energy

The potential energy associated with tides can be harnessed by building barrage structures built across the mouth of a bay or an estuary in an area with a large tidal range. As the level of the water changes with the tides, a difference in hydraulic heads develops across the barrage. Sea water is allowed to flow through the barrage via turbines, which can provide power during either the ebb tide or flood tide or during both tides. This generation cycle means that, depending on the site, power can be delivered twice or four times per day on a highly predictable basis. Tidal power potentials

Table 2
Research project for wave energy converter in Korea.

Project	Type of converter	Structure	Power capacity (kW)	Period	Remarks
Jujeon-A	OWC	Floating	60	1993–2001	Pilot plant in 2001
Water Reservoir WEC	Wave overtopping	Caisson	250	2003–2005	Basic research
Yongsoo 500 kW OWC	BBDB OWC	Caisson	500	2003–2012	Pilot plant in 2012
Reef with vanes	Wave overtopping	Monopile	250	2007–2010	Optimal design for pilot plant
Liquid column oscillator	Attenuator	Floating	300	2010–2011	Prototype test in 2011
Hydraulic pumping WEC	Point absorber	Floating	200	2010–2011	Prototype test in 2011

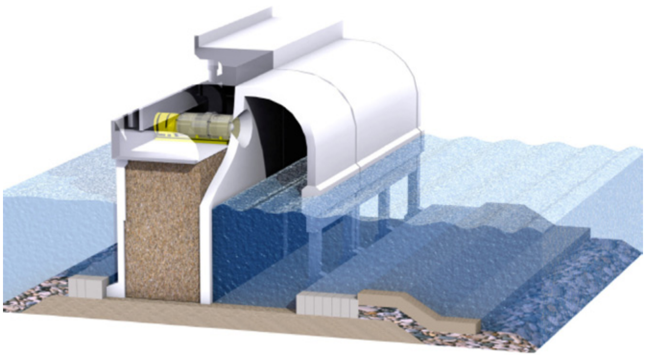

Fig. 6. Schematic design of caisson-type 500 kW wave energy converter.

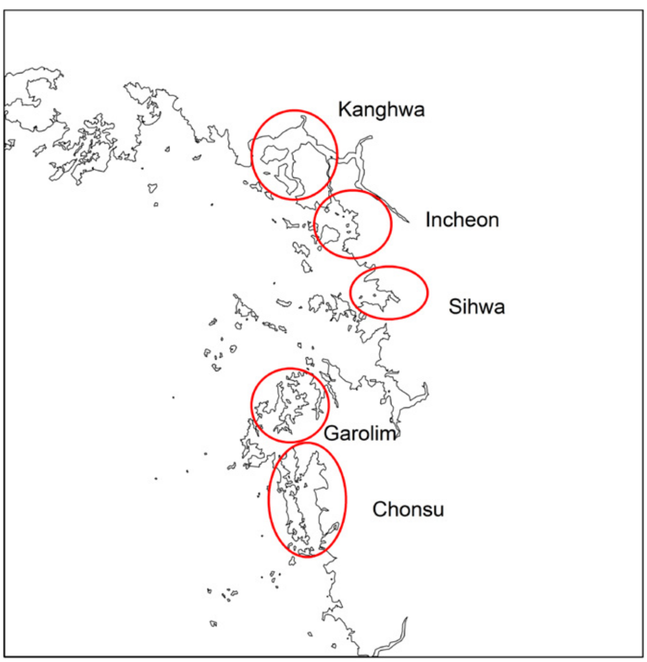

Fig. 7. Tidal power plant Candidate locations.

are determined by the selection of location and the capacity of the energy converter.

4.1. Tidal energy investigation

The middle part of the Korean western coast is one of the most promising places for harnessing tidal energy in the world. Fig. 7 shows five candidate sites for developing tidal energy in Korea. The substantial magnitudes of tidal ranges on the western coast have prompted studies of tidal energy in Korea since the 1930s [1], and further investigations continued intermittently. An extensive study was initiated by Korea Electric Power Corporation (KEPCO) since the 1970s [19–30]. In particular, the R&D project of 'Korea tidal power study: Phase 1′ was conducted to investigate the feasibility of tidal power development on the west coast of Korea [24]. The project confirmed that approximately 6500 MW tidal powers could be developed at 10 possible sites.

The first feasibility study on the Garolim Tidal Power Plant was carried out by SOGREAH of France in 1980 and 1981 [23]. The principal conclusion of this investigation was that a technically and economically acceptable development would be feasible, and as a result, it was decided that a construction of the tidal power station would commence. However, another feasibility study [26] initiated from 1984 concluded that the tidal power plant was not economically feasible due to the low price of oil and the high construction cost at that time, and recommended to postpone the construction of a tidal power plant. Recently, the feasibility of Garolim tidal development came to the fore again because of the increased requirements of renewable energy development. KORDI [28] presented that the B/C (Benefit/Cost) ratio is over 1.0, and thus concluded again that Garolim tidal development might be economically feasible.

In addition to Garolim Bay, the feasibility of tidal power development in Incheon Bay was investigated in 2008 [31], and research on the environmental impact that accompanied by the construction of the barrier has been studied since 2009. KORDI also studied the feasibility of Kanghwa tidal plants from 2007 to 2009 in view of maximizing the available energy output [32]. Chonsu Bay had been considered one of the major candidate sites, but the coastal development, including the reclamation project in the 1970s and 1980s, reduced the available size of the reservoir as well as the tidal range, and the development of the tidal power plant thus became economically less feasible. Details on the suggested tidal power plant for each site are listed in Table 3.

4.2. Sihwa Tidal Power Plant

In 2011, Korea opened the world's largest tidal power plant at Sihwa Lake reservoir, about 60 km southwest of Seoul, to meet the electricity demand, and is conducting a trial run on the plant at present. Upon completion, the plant will be able to supply a total power output capacity of 254 MW, surpassing the 240 MW of Rance Tidal Power Station to become the world's largest tidal power installation [33].

The tidal barrage makes use of a 12.4 km seawall constructed in 1994 (Fig. 8). This seawall was originally constructed for flood mitigation and agricultural purposes, and the lake was designed as a freshwater lake. However, after the embankment was constructed, the water quality in this area seriously deteriorated as the project progressed. Large volumes of industrial waste from the Ansan industrial complex were being discharged into the lake, and the pollution became an increasing problem. As an alternative measure for improving the water quality, it was decided that the lake would be changed from a fresh water lake to a seawater lake. The Korea Water Resources Corporation (KOWACO) has carried out a feasibility study of the Sihwa tidal projects involving preliminary and execution designs [34].

The Sihwa Tidal Power Plant, with a total project cost of approximately USD 355 million, consists of a powerhouse containing 10 bulb-type turbines with direct driven generators, gates and

Table 3
Tidal power plant candidate locations.

Site	Spring tidal range (m)	Basin area (km^2)	Turbine capacity (MW)	Annual energy (GWh)	Generating type
Sihwa	7.8	43	254	553	Flood
Garolim	6.7	96	520	950	Ebb
Incheon	7.7	157	1320	2214	Ebb
Kanghwa	7.6	83	840	1556	Ebb
Chonsu	5.9	146	720	1207	Ebb

Fig. 8. Location of the Lake Sihwa Tidal Power Plant Site.

Fig. 9. Photograph showing the Lake Sihwa Tidal Power Plant.

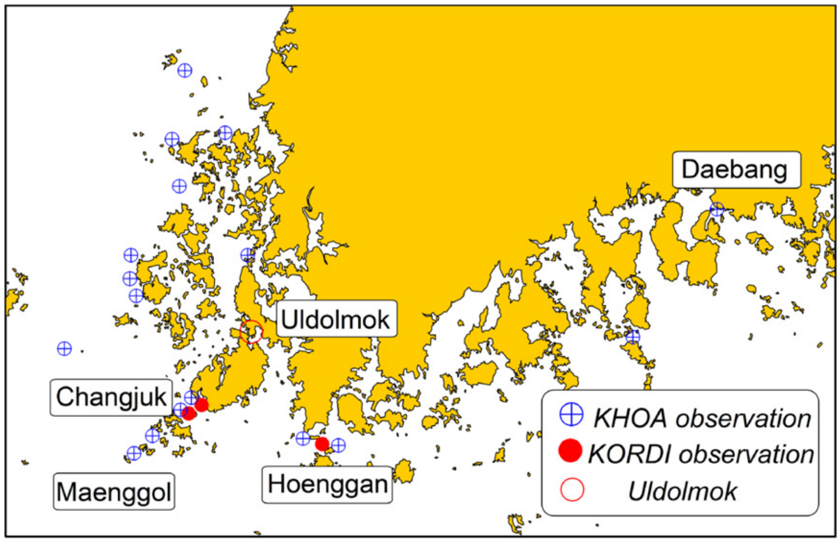

Fig. 10. Candidate sites to utilize tidal current energy and locations of tidal current observation.

other equipment (Fig. 9). The installed capacity of the turbines and generators is 254 MW (25.4 MW × 10 bulb-type units with runner diameters of 7.5 m at 64.29 rpm). Eight units of culvert (B 15.3 m × H 12.0 m) are installed in the sluice gate. The mean operating tidal range is 5.6 m with a spring tidal range of 7.8 m. The working basin area was originally intended to be 43 km^2, but this has been reduced by land reclamation and freshwater dykes. The basin will eventually be around 39 km^2. The annual energy output is expected to be approximately 552.7 GWh.

5. Tidal current energy

To utilize the tidal current energy, tidal current devices are placed directly in-stream and they generate energy from the flow of the tidal current, rather than using a dam structure. In general, currents in water channels with a maximum flow speed of more than 2 m/s have practical applicability. Tidal current is mainly caused by the gravitational pull of the sun and the moon, which is strong in a certain coastal areas due to the topology and the tidal conditions that force the water to flow through narrow channels at high speed. Korea is adjacent to the Yellow Sea, which is well known to have a high tidal level. A ria shoreline has developed along the south-western coast, and thus there are many candidate locations to harness the tidal current energy. In this review, we collected existing observation data and established an ocean circulation model to investigate the candidate sites for the utilization of tidal current energy. The Uldolmok tidal current energy power

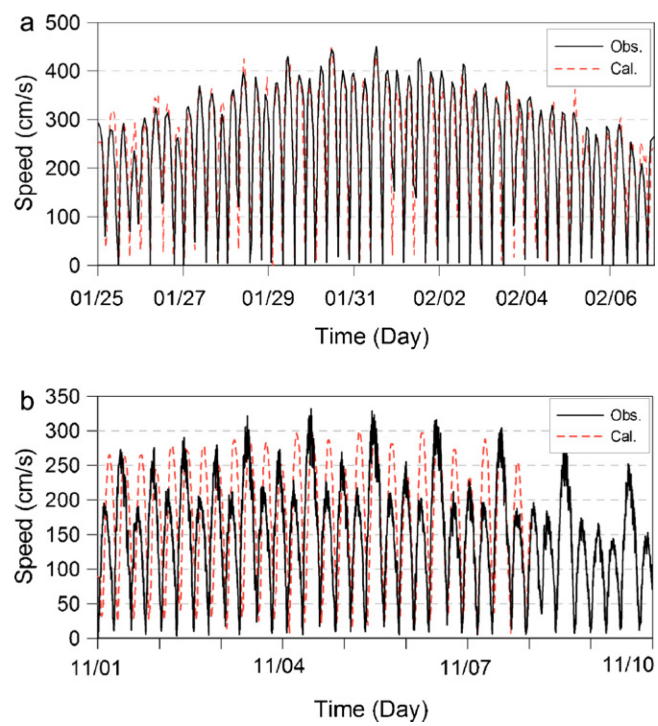

Fig. 11. Observed and calculated tidal current speeds: (a) Uldolmok and (b) Changjuk.

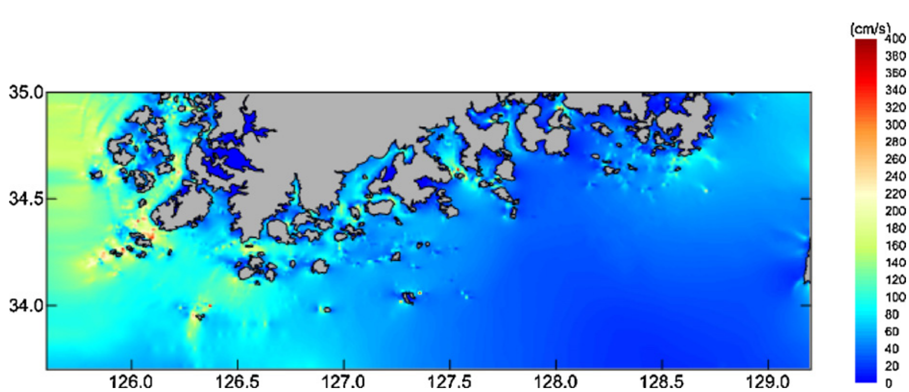

Fig. 12. Distributions of maximum tidal current speed in the southern sea of Korea.

Fig. 13. Pilot test of Uldolmok Tidal Power Plant.

plant project which has been conducted since 2008 is also briefly introduced.

5.1. Observation data

In the south-western coastal region where there are many locations that are known to have relatively high tidal current speeds, many tidal current observations have been conducted. KHOA [35] has observed tidal levels and tidal currents in many sites around Korea since the 1960s, as shown in Fig. 10. These observations were conducted to obtain the tidal current information on the south-western coast where tidal current patterns are very complex because of the ria coast. From these data, several candidate locations for tidal current energy were identified. In particular, the tidal current in Uldolmok Channel has the highest tidal current speed reaching approximately 6.5 m/s at maximum. In addition, the Changjuk, Maenggol, Hoenggan, and Daebang Channels, where maximum current speeds exceed 2.5 m/s are also good candidates to harness the tidal current energy. Recently, KORDI conducted detailed field observation to investigate the tidal current energy potentials in Changjuk and Hoenggan Channels as shown in Fig. 10.

5.2. Numerical model

KORDI [4] established a numerical model to simulate the tidal currents at the southern sea of Korea. This numerical model solves the 2-D depth-integrated nonlinear shallow water equation including the horizontal turbulent advection term [36,37]. The grid size of the model was set to 185 m which yields enough resolution to analyze the spatial distribution of tidal current energy. The numerical results were validated using collected observation data from KHOA and KORDI tidal current measurements. Fig. 11 shows a comparison of the numerical solution and the observation data at Uldolmok and Changjuk Channel, which shows good agreement considering that only five constituents are modeled. Fig. 12 shows the distribution of the maximum tidal current velocities obtained from the numerical simulation, which is the depth-averaged tidal current velocity. In the south-western coastal region, high tidal currents are observed. The total amount of tidal current energy available is approximately 5900 MW in Korea, but the economically feasible amount is estimated to be approximately 470 MW in the channels of the south-western coasts [5]. The tidal current energy potentials in the candidate channels are given in Table 4.

Fig. 14. In situ experimental system of hellical type turbine.

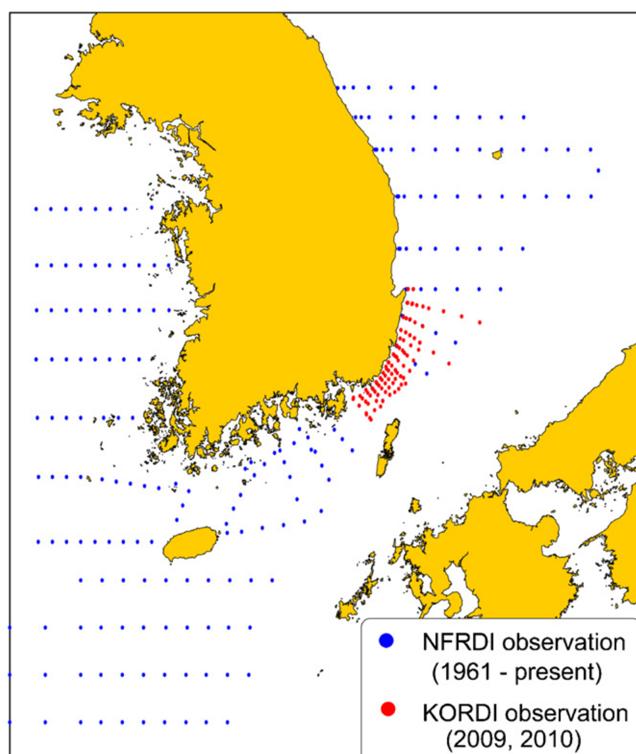

Fig. 15. Locations of periodic CTD observation by NFRDI and intensive observation by KORDI.

Table 4
Tidal current power plant candidate locations.

Channel	Mean depth (m)	Width (m)	Maximum current speed (m/s)	Maximum energy potential (kW)	Annual energy (MWh)
Uldolmok	20	300	6.50	366,354	122,171
Changjuk	30	3500	3.59	1,867,359	360,206
Maenggol	45	4200	3.49	3,088,113	595,684
Hoenggan	30	2000	2.50	360,352	69,510
Daebang	15	250	2.50	22,522	4344

5.3. Uldolmok tidal current power plant

Uldolmok is a narrow channel (320 m wide in average) that divides the mainland of Korea and Jindo Island. The topography of this region has a very irregular and complex shape because the bedrock on the seabed is not covered with a sediment layer. Around Uldolmok, the difference between maximum and minimum tidal elevation is only 3 m, but a 2 m difference in water elevation between each end of the channel generates very strong seawater flow across the neck. The maximum depth-averaged velocity observed was up to 5.35 m/s according to the current measurement data of 2002.

KORDI has been focusing on developing technology related to the generation of tidal current energy that can be put into practical use at Uldolmok narrow channel since 2001 [38–40]. In May 2009, the construction of a 1000 kW pilot power plant for current energy with helical turbines [41] was completed (Fig. 13). Three helical turbines were installed on one axis of a generator as shown in Fig. 14; each turbine generates 500 kW of electricity.

After several tests, verification tests for the effectiveness and optimization technique of the energy generation system were implemented. At the same time, the commercialization plan for the Uldolmok Power Plant was established based on the test results of the test plant. It is predicted to be possible to produce 123 GWh

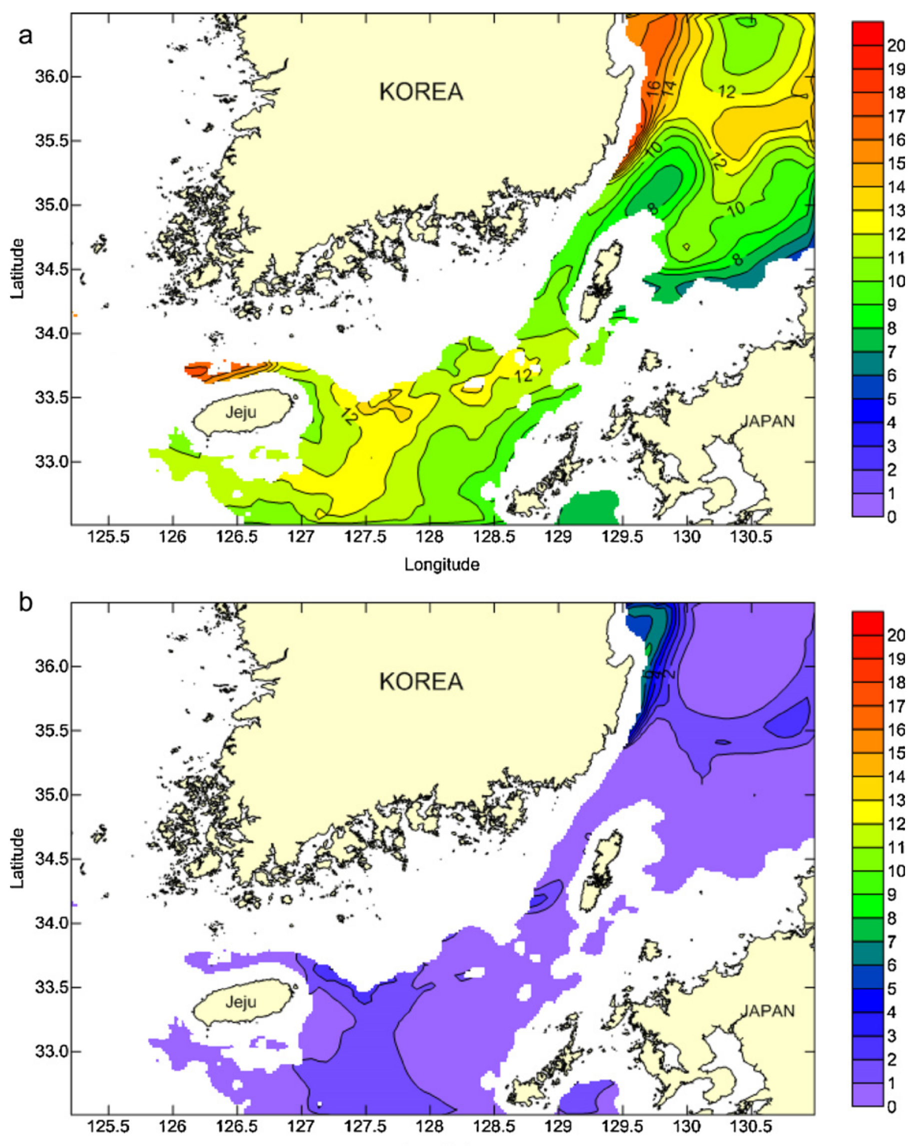

Fig. 16. Temperature differences between surface and depth of 100 m: (a) August (summer) and (b) December (winter).

electricity per year in this power plant, which can fulfill the energy consumption needs of approximately 21,000 households [42].

6. Ocean thermal energy

Ocean thermal energy conversion uses the difference between the cooler deep and warmer shallow or surface ocean waters to run a heat engine and produce electricity. As a result of solar heating, the top layer of the water is much warmer than deep ocean water. Where the temperature difference between the warmer top layer and the colder deep water is approximately 20 °C, the conditions for ocean thermal energy conversion are favorable. These conditions exist mainly around the coastal area located close to the equator.

The ocean thermal energy in Korea is actually very low. Average water depths in the Yellow Sea and the southern sea are only, 44 m and 101 m, respectively, which is so shallow that the temperature difference is not high. In contrast, the average water depth reaches 1500 m in the East Sea where a relatively high temperature difference is found. In this section, the periodic observations of water temperature in Korea are summarized and the distribution of temperature differences is presented by a numerical simulation.

The observation data of water temperature around Korea are periodically observed by NFRDI. Since 1961, NFRDI has performed bimonthly observations for 25 lines including 207 points with vertical observation points at 0, 10, 20, 30, 50, 75, 100, 125, 200, 250, 300, 400, and 500 m water depth. The observation locations are depicted in Fig. 15. The observed data are provided on their website [43]. The observation data showed that the mixing layer is developed at a depth between the surface and 20–100 m. A thermocline, where the temperature changes more rapidly with depth than it does in the layers above or below, was observed below the mixing layer.

In the recent R&D project [4], KORDI performed intensive CTD (Conductivity-Temperature-Depth) profiler observations in 2009 and 2010 in the south-eastern sea where the thermal difference is relatively high. The observation locations are marked in Fig. 15. The observed data was also used to verify the numerical model to investigate the temperature distribution around the southern sea of Korea.

KORDI [4] performed numerical modeling to assess the distribution of ocean thermal energy using ROMS (Regional Ocean Modeling System), which is a free-surface, hydrostatic, primitive ocean model that uses stretched, terrain-following coordinates in the vertical and orthogonal curvilinear coordinates in the horizontal. The numerical model was described in detail by Shchepetkin and McWilliams [44]. The numerical model was calibrated using the observation data of NFRDI and KORDI. The monthly ocean thermal differences were computed at 30, 50, 70, and 100 m water depth. Fig. 16 shows the thermal differences between the surface and a depth of 100 m in August and December, which represent the typical climate conditions of summer and winter, respectively. Because the water depth at the southern sea and the Yellow Sea is less than 100 m, the results of these areas are treated as null values. In summer, high temperature differences appear in the south-eastern nearshore regions, and the differences are observed to be 19 °C at most. However, except for the summer, the temperature differences were very low for the whole surrounding sea.

It appears that assessing the amount of ocean thermal energy around Korea is meaningless and impetuous because the temperature differences are relatively low and the energy output is highly dependent on the efficiency of the energy converter, but the development of an ocean thermal energy convertor is still in its infancy. Nevertheless, the information on the seasonal variations and the spatial distributions of thermal differences obtained by the numerical results will be useful for related research in Korea.

7. Conclusions

An overview of the assessment of the ocean renewable energy and its technical developments in Korea was presented in detail in this paper. The development of ocean energy conversion is underway and it is expected that this will contribute considerably to the increase in electric power production, to the protection of the environment, and to the economic growth of Korea. Although Lake Sihwa Tidal Power Plant is being constructed and many R&D projects to exploit ocean renewable energy are underway, the renewable energy market in Korea is currently in an early stage. In addition, from an economic standpoint, wave energy and ocean thermal energy are currently not as cost-effective as fossil fuels. Therefore, the overall demand for these types of energy is not expected to increase significantly under these circumstances. The government should provide assistance to relevant enterprises, in the form of tax incentives and financial support, to help reduce the investment cost of producing new and recycled energy through technological innovation, and to stimulate demand for their usage. Intensive investments will accelerate the technical development of ocean energy. In addition, many obstacles should be cleared before its commercialization, particularly in technology development, location designation and market creation. Given the rapidly changing market conditions and competitive environment, a comprehensive approach rather than a consecutive one is necessary to create actual businesses from research achievements. With the support of national policies, technological development, and a well-functioning market, ocean energy will achieve greater development in the future and contribute more to the national economy.

Acknowledgement

This study was supported by New & Renewable Energy R&D Program (2008-N-OC04-P-01) under the Korea Ministry of Knowledge Economy. Thanks are also extended to KORDI (Project No. PE98603) for providing financial support.

References

[1] Chosun Geverner's Office. Tidal power. Bureau of Communication; 1930 [in Japanese].
[2] KORDI. A study on the atlas of marine resources in the adjacent seas to Korea; 1990 [in Korean].
[3] KEPCO. A study on the development of ocean thermal energy conversion and wave power generation system; 1990 [in Korean].
[4] KORDI. Study of the distribution of ocean energy resources in the southern sea of Korea; 2011 [in Korean].
[5] New & renewable energy white book; 2010 [in Korean].
[6] Yearbook of energy statistics; 2010.
[7] Korea Energy Economics Institute. Energy Info., Korea; 2010.
[8] Oh W, Lee K. Energy consumption and economic growth in Korea: testing the causality relation. J Policy Model 2004;26:973–81.
[9] Lee SK, Mogi G, Kim JW. Energy technology roadmap for the next 10 years: the case of Korea. Energy Policy 2009;37:588–96.
[10] Korean Ministry National Energy Master Plan; 2008 [in Korean].
[11] Kim G, Jeong WM, Lee KS, Jun K, Lee ME. Offshore and nearshore wave energy assessment around the Korea Peninsula. Energy 2011;26:1460–9.
[12] Lee DY, Jun KC. Estimation of design wave height for the waters around the Korean Peninsula. Ocean Sci J 2006;41:245–54.
[13] Günter H, Rosenthal W, Wears TJ, Worthington BA, Hasselmann I, Ewing JA. A hybrid parametrical wave prediction model. J Geophys Res 1979;84(C9):5727–38.
[14] The WAMDI Group. The WAM Model – a third generation wave prediction model. J Phys Oceanogr 1988;18:1775–810.
[15] KORDI. Development of wave energy converter (60 kW) using ocean energy; 2011 [in Korean].
[16] KORDI. Principal research in wave overtopping power generation technology; 2003 [in Korean].
[17] KORDI. Development of wave energy utilization system; 2005 [in Korean].
[18] Ahn KK, Tuong DQ, Tien HH, Yoon JI. An innovative design of wave energy converter. Renew Energy 2012;42:186–94.
[19] Korea Electric Company. Tidal power generation; 1970 [in Korean].
[20] KORDI. Feasibility Study of Tidal Power Plant. Report to the Korean Ministry of Science and Technology; 1974 [in Korean].

[21] KORDI. Pre-feasibility study of tidal power plant at Chonsu bay; 1975 [in Korean].
[22] SOGREAH. Tidal power schemes on the west coast. Report to the Korean Ministry of Construction; 1973.
[23] SOGREAH. Garolim tidal power plant, feasibility studies, summary report and vol. I–X. Prepared for Korea Electric Co.; 1981 [in Korean].
[24] KORDI. Korea tidal power study – phase I; 1978 [in Korean].
[25] Korea Research Institute of Ship and Ocean. Pre-feasibility study of tidal power development (Incheon Bay); 1978 [in Korean].
[26] KORDI. Korea tidal power study; 1986 [in Korean].
[27] KORDI. Feasibility study on Garolim tidal development. Report to Korea Electric Power Corp.; 1993 [in Korean].
[28] KORDI. Development of utilization technique for ocean energy (I): tide and tidal current energy. Korea: Ministry of Maritime Affairs & Fisheries; 2001 [in Korean].
[29] KORDI. Development of utilization technique for ocean energy (I): tide and tidal current energy. Korea: Ministry of Maritime Affairs & Fisheries; 2002 [in Korean].
[30] Korea Western Power. Feasibility study on Garolim tidal development; 2005 [in Korean].
[31] KORDI. Feasibility study on Incheon Bay tidal development; 2008 [in Korean].
[32] KORDI. Feasibility study on Kanghwa tidal development; 2010 [in Korean].
[33] Bae YH, Kim KO, Choi BH. Lake Sihwa tidal power plant project. Ocean Eng 2010;37:454–63.
[34] KOWACO. Basic design report for Sihwa Lake tidal power construction; 2004 [in Korean].
[35] http://www.khoa.go.kr.
[36] Kang SK, Chung JR, Lee SR. Seasonal variability of the M2 tide in the adjacent sea to Korea. Cont shelf Res 1995;15:1087–113.
[37] Kang SK, Yum KD, Lee KS, Park JS. Tide and tidal current characteristics and tidal current power generation in the Uldolmok waterway. In: Conference on new and renewable energy. 2006. p. 141–4.
[38] Lee KS, Yum KD, Kang SK, Park JS, Park WS, Han SH, et al.Development of power generation system using tidal current in Uldolmok. 2005. p. 6104–15.
[39] Han SH, Lee KS, Yum KD, Park WS, Yi JH. Efficiency assessment of turbine for tidal current power plant by in-field experimental test. In: Conference on new and renewable energy. 2006. p. 517–20.
[40] Oh MH, Lee KS, Yum KD, Park WS, Han SH, Park JS, et al. Design parameters for pilot tests of 1 MW tidal current power generation. In: Conferences on new and renewable energy. 2006. p. 130–3.
[41] Grolov AM. Helical turbines for harnessing zero-head hydro and wind energy. Assembly Environmental Forum; 1999.
[42] KORDI. Development of utilization technique for tide and tidal current energy (1st Phase); 2006 [in Korean].
[43] http://www.kodc.nfrdi.re.kr.
[44] Shchepetkin AF, McWilliams JC. The Regional Ocean Modeling System (ROMS): a split-explicit, free-surface, topography-following-coordinate ocean model. Ocean Model 2005;4:347–404.